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### ***published in***

Journal of Orthopaedic and Sports Physical Therapy  
2019

### ***DOI (link to publisher)***

[10.2519/jospt.2019.7916](https://doi.org/10.2519/jospt.2019.7916)

[Link to publication in VU Research Portal](#)

### ***citation for published version (APA)***

Van Dieën, J. H., Peter Reeves, N., Kawchuk, G., Van Dillen, L. R., & Hodges, P. W. (2019). Analysis of motor control in patients with low back pain: A key to personalized care? *Journal of Orthopaedic and Sports Physical Therapy*, 49(6), 380-388. <https://doi.org/10.2519/jospt.2019.7916>

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1     **Analysis of motor control in low-back pain patients, a key to personalized care?**

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33  
34    **conflict of interest:** The authors have no conflict of interest to report.

35  
36    This paper reports a literature review, not supported by specific funding. Ethical approval does not  
37    apply.

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39

## 40    **Synopsis**

41    Motor control exercise has been shown to be effective in the management of low-back  
42    pain (LBP), but effect sizes are modest, possibly due to the fact that studies have used  
43    a one-size-fits-all approach, whereas literature suggests that patients may differ in  
44    presence or type of motor control issues. In this commentary, we address the question  
45    whether consideration of such variation in motor control issues might contribute to  
46    more personalized motor control exercise for patients with LBP. Such an approach is  
47    plausible, since motor control changes may play a role in persistence of pain through  
48    effects on tissue loading that may cause nociceptive afference in particular in case of  
49    peripheral sensitization. Subgrouping systems used in clinical practice which comprise  
50    motor control aspects allow reliable classification that is in part aligned with findings  
51    in studies on motor control in patients with LBP. Motor control issues may have  
52    heuristic value for treatment allocation, as the different presentations observed suggest  
53    different targets for motor control exercise, but this remains to be proven. Finally,  
54    clinical assessment of patients with LBP should take into account more aspects than  
55    motor control alone, including pain mechanisms, musculoskeletal health and  
56    psychosocial factors, and may need to be embedded in a stratification approach based  
57    on prognosis to avoid undue diagnostic procedures.

58

59    **Keywords:** back pain, postural control, exercise, diagnostics, subgrouping

60 In the treatment of low back pain (LBP), exercise that targets motor control is  
61 commonly used and with some success.<sup>10, 49, 75</sup> Motor control can be defined as the way  
62 in which the nervous system controls posture and movement to perform a given motor  
63 task and includes consideration of all the associated motor, sensory and integrative  
64 processes. Here we use the term “motor control exercise” (MCE) to refer to exercise  
65 that aims to change the manner in which a person controls their body (including  
66 posture/alignment, movement, muscle activation) to modify loading of the spine and  
67 adjacent structures.

68

69 The effectiveness of MCE has been the subject of several systematic reviews that have  
70 undertaken different comparisons.<sup>10,49,75</sup> A consistent outcome is that MCE is better than  
71 minimal intervention in reducing pain in the short-, intermediate- and long-term, and in  
72 reducing disability at long-term follow-up.<sup>49</sup> The pooled effect size was ~14% for pain  
73 and ~11% for disability when compared to minimal intervention.<sup>49</sup> Effects were better  
74 than for many other interventions, although they were still modest and only better than  
75 other exercise interventions in the short-term.<sup>49</sup> Recent systematic reviews provide  
76 contrasting evidence for comparison of effects of MCE and general exercise on  
77 disability: one reported better outcomes for MCE;<sup>10</sup> the other concluded there is low to  
78 high quality evidence that MCE is not clinically more effective than other exercises.<sup>75</sup>  
79 Of note, most large clinical trials with modest effects investigated application of MCE  
80 in a standardised manner to a heterogeneous group of patients with non-specific LBP.  
81 This contrasts the prevailing clinical view that treatment effects may be larger if  
82 treatments are targeted to the right patients, at the right time, and in a tailored,  
83 individualized manner. This has been the topic of considerable research and clinical  
84 attention.

It has been suggested that specific patient characteristics may predict who will or will not benefit from MCE,<sup>48</sup> or guide how it should be tailored to the individual patient. As reviewed by van Dieën et al.,<sup>94</sup> laboratory studies of motor control in individuals with LBP and healthy subjects demonstrate high variability between studies,<sup>e.g. 52, 95</sup> and between individuals with LBP within studies.<sup>e.g. 16, 72</sup> This concurs with the proposal that tailored rehabilitation programs are likely to be required to address the specific changes in motor control that are unique for the individual.

This commentary aims to address the overall question whether features of motor control could form an important element of a subgrouping scheme. Individualisation of MCE could involve identification of subgroups of patients with similar motor control issues or similar response to treatment, or individualising treatment to match each individual patient's presenting characteristics. A further aim is to highlight the research and development that is needed to address the major issues of subgrouping, particularly related to motor control, for application in clinical practice.

## **2 Subgrouping of patients with LBP**

Based on diversity in presentation among individuals with LBP, it has been argued that no single treatment is likely to be effective for all patients and various authors have emphasized the need to administer more personalized treatment.<sup>6, 7, 27, 97</sup> Subgrouping of patients is generally considered to be a step towards personalization, and LBP is seen as a disorder for which subgrouping may be particularly useful in view of the large and heterogeneous patient population, the large variation in treatment outcomes, and the variety of available treatment options with varying costs and risks. Among clinicians it is generally believed that LBP includes many different conditions.<sup>27</sup> Consensus on the best way to subgroup patients or to personalize treatment is, however,

110 lacking<sup>38, 97</sup> and there is no strong evidence yet for effectiveness of subgroup-based  
111 treatment.<sup>5, 24, 33, 45, 54</sup>

112 Towards resolution of the issues addressed above, Foster et al.<sup>26</sup> proposed a set  
113 of requirements for subgrouping in LBP. First, the subgrouping system should be  
114 plausible; in other words, it should be compatible with current knowledge about  
115 pathology of and risk factors for LBP. Second, subgrouping should be reliable; for  
116 instance, repeated testing or testing by different clinicians should assign the same  
117 patients to the same subgroups. Third, methods need to be simple enough to allow  
118 application in clinical practice. The simplicity of a method must be balanced with  
119 acceptability to patients and clinicians, and cost-effectiveness. Very sophisticated  
120 diagnostic instruments can be useful if the outcomes allow more effective treatment at  
121 a lower overall cost. Fourth, for clinical utility a subgrouping system should yield  
122 mutually exclusive subgroups, meaning all cases, at one point in time, should fit into  
123 only one subgroup and this subgroup membership should guide a unique treatment  
124 choice. In the following sections, we review motor control subgrouping based on the  
125 criteria proposed by Foster et al..<sup>26</sup>

126

### 127 **3 Is subgrouping based on motor control plausible?**

128 For subgrouping based on motor control to be plausible, issues with motor  
129 control would have to be relevant for the development or continuation of LBP and  
130 relevant variation in motor control presentation would have to exist in the population  
131 of individuals with LBP.

132 With respect to the first question, the nature of loads on the spine and adjacent  
133 structures depends on the quality of motor control, in combination with anatomical  
134 factors (e.g. muscle moment arms) and motor tasks that are performed. However,

135 whether loading of these structures is relevant with respect to development of LBP has  
136 been heavily debated.<sup>3, 4, 42, 43, 53, 66, 83, 93</sup> Recent systematic reviews and meta-analyses,  
137 however, provide consistent evidence for a prospective association between some  
138 activities and tasks that induce high mechanical loads on the back and LBP.<sup>11, 14, 30</sup> In  
139 addition, variables that quantify (cumulative) mechanical load on lumbar tissues, such  
140 as lumbar moments and compression forces, are associated with LBP incidence or  
141 prevalence.<sup>12, 13, 40, 51, 61</sup> Another line of evidence for the plausibility of a causal relation  
142 between mechanical loading and LBP stems from biomechanical studies in animal  
143 models and on human cadaveric material. Such studies indicate that loads on spinal  
144 tissues that occur in daily life can cause injury<sup>8, 81</sup> and, even without injury, ongoing  
145 mechanical stimulation of tissues can potentially activate nociceptors and initiate an  
146 inflammatory response.<sup>47</sup> Although, it is difficult to confirm the presence of micro-  
147 trauma let alone non-injurious noxious stimulation of tissues in the back in individuals  
148 with LBP, a range of literature supports the plausibility of a causal relation between  
149 mechanical loading and the development of LBP.<sup>96</sup> Finally, several mechanisms can  
150 play a role in transition to chronic LBP, specifically non-healing of injured tissues,  
151 ongoing nociceptive input, central sensitization and neuropathic pain development.  
152 Mechanical loading of tissues would be relevant in relation to the first two of these. It  
153 may both hamper and stimulate tissue healing, likely dependent on intensity and  
154 frequency of loading and time after injury,<sup>23, 46, 82</sup> and also in the absence of frank injury  
155 it can promote ongoing nociceptive input, especially in the presence of peripheral  
156 sensitization.<sup>19, 59, 103</sup>

157         With respect to the question whether there is relevant variation in motor control  
158 presentation among individuals with LBP, a recent review of the literature concluded  
159 that the group with LBP may show overlap with or be at either extreme of the

160 distribution in motor control found in healthy participants.<sup>94</sup> The groups deviating from  
161 normal motor control can be divided based on the mechanical consequences of the  
162 changes in motor control. One pattern of change involves increased activation of trunk  
163 muscles and may provide tight control over lumbar movements, but at the cost of higher  
164 loads on muscles and on the spine.<sup>91</sup> The opposite pattern, involves lower muscle  
165 activation and might avoid high muscle forces and compressive loading, but with the  
166 cost of a loose control over movement and a potential result of higher tensile strains of  
167 tissues. In the following we will refer to these two ends of a spectrum as “tight” and  
168 “loose” control. Clearly tight and loose control would have different mechanical  
169 consequences that could both be relevant for development and continuation of LBP, but  
170 they also suggest different targets for MCE.

171

#### 172 **4 Is subgrouping based on motor control practically applicable and reliable?**

173 Studies on motor control in LBP, summarized in van Dieën et al.,<sup>94</sup> have used a  
174 broad range of laboratory-based measurement techniques to characterize motor control.  
175 In principle, these techniques could provide a basis for the development of clinical tests  
176 to assess motor control to inform clinicians regarding subgrouping. However, generally  
177 speaking application of these techniques involves substantial costs and requires specific  
178 expertise that is not readily available. Therefore, the following considers the extent to  
179 which subgrouping systems already applied in clinical practice take motor control  
180 aspects into account and to what extent this results in reliable classification.

181 Several systems for subgrouping or profiling that are in common use clinically  
182 incorporate motor control aspects in the assessment of patients with LBP. Those that  
183 have been studied most extensively are, the “Treatment Based Classification” (TBC),  
184 the “Multi-Dimensional Clinical” framework (MDC) (formerly named the “O’Sullivan



Classification”), and the “Movement System Impairment” classification (MSI). If these assessments capture the differences in motor control that have been identified in laboratory-based motor control measures, this would indicate that assessment of motor control issues based on clinically applicable tools can yield reliable outcomes.

#### 4.1 Treatment Based Classification

The TBC system, originally proposed by Delitto et al.,<sup>18</sup> and updated by Fritz et al.<sup>28</sup> and Alrwaily et al.<sup>1</sup> proposes four LBP subgroups, each named for the treatment to which the patient is most likely to respond; (1) manipulation, (2) stabilization, (3) specific exercise, and (4) traction. The inter-rater reliability of examiners (physical therapists who are familiar with the classification system) to classify patients is clinically acceptable.<sup>97</sup>

With respect to the current understanding of motor control changes in LBP,<sup>94</sup> the criterion of hypomobility of the lumbar spine, as one of the criteria for allocation to the TBC *manipulation* subgroup, could be considered to align with a group of patients with LBP who present with tight motor control. Importantly, other criteria for subgroup allocation (e.g. time since symptom onset, age) cannot be considered specific to this motor control phenotype. Furthermore, it would seem plausible that the TBC *stabilization* subgroup could involve individuals who use loose motor control,<sup>94</sup> as this group are described to require restriction of excessive segmental motion. Consistent with this proposal, studies report that individuals classified into this group more often have excessive segmental rotations or translation on flexion/extension radiography than others,<sup>29</sup> more aberrant segmental lumbar movement on flexion/extension radiography,<sup>84</sup> poorer ability to contract the transversus abdominis muscle in isolation from other abdominal muscles,<sup>85</sup> and lower multifidus activation,<sup>32</sup> which could all be considered to align the loose motor control phenotype.

## 210 4.2 *Multi-Dimensional Clinical framework*

211 The MDC framework has evolved from a subgrouping approach<sup>62</sup> to a  
212 multidimensional clinical profiling approach.<sup>65</sup> Within the MDC, motor responses are  
213 described in three broad contexts: adaptive/protective motor responses to an acute tissue  
214 injury and or underlying pathological process (i.e. “movement impairment”), motor  
215 responses secondary to dominant central pain mechanisms, or maladaptive/provocative  
216 motor responses that may contribute to the pain (i.e. “motor control impairment”).  
217 These presentations may be associated with directional patterns of pain provocation  
218 (flexion, extension, rotation, side bending) or multiple directions (multidirectional).<sup>69</sup>  
219 Reliability testing among trained physical therapists has shown good to excellent inter-  
220 rater reliability in classification of patients.<sup>17, 99</sup>

221 There is strong potential alignment between the MDC characterisation of motor  
222 responses and the tight and loose motor control phenotypes of LBP. The movement  
223 impairment presentation aligns well with motor control changes interpreted as tight  
224 motor control. The MDC movement impairment is characterized by abnormally high  
225 levels of muscle guarding and co-contraction of trunk muscles.<sup>62</sup> Whether the  
226 subdivision on the basis of the movement direction avoided by the individual aligns  
227 with detailed assessment of motor control has not been tested.<sup>69</sup> The motor control  
228 impairment presentation, which is described as demonstrating “an impairment or deficit  
229 in the control of the symptomatic spinal segment in the primary direction of pain”, can  
230 be hypothesized to overlap with the loose control end of the spectrum of motor control  
231 changes. This applies in particular to the flexion presentation, who tend to adopt flexed  
232 trunk postures, which provoke pain. These individuals gradually increase trunk flexion  
233 over time when cycling,<sup>9</sup> or when seated,<sup>16, 64</sup> less accurately resume a “neutral” trunk  
234 posture (perhaps caused by proprioceptive impairment<sup>60, 63</sup>), may have lumbar

235 hypermobility in forward bending,<sup>41</sup> and lower lumbar muscle activity in sitting.<sup>15</sup> The  
236 “passive extension” sub-group, who tend to hinge into extension with low trunk muscle  
237 activity,<sup>62</sup> may also align with a loose control group, while the “active extension”  
238 subgroup, who tend to adopt extended trunk postures characterized by high muscle  
239 activity,<sup>15, 16</sup> appear more aligned to a tight control phenotype.

#### 240 **4.3 Movement System Impairment classification**

241 The MSI classification system, developed and described by Sahrman,<sup>73</sup> has the  
242 underlying assumption that people with LBP tend to move one or more lumbar joints  
243 more readily than adjacent joints/segments (e.g. thoracic or hip joints). This is thought  
244 to result from habitual movement patterns during daily activity, eventually leading to  
245 excessive loading of tissues associated with the specific joint. Five LBP subgroups are  
246 proposed, named for the specific direction(s) of lumbar movement considered to  
247 contribute to the patient’s symptoms: flexion, extension, rotation, rotation with flexion,  
248 and rotation with extension. Trained physical therapists can attain fair to excellent  
249 reliability in MSI classification.<sup>97</sup>

250 The MSI system describes motor impairments in LBP as a failure to constrain  
251 movement of some lumbar joints in a specific direction. This concurs with the notion  
252 of loose control, and the MSI system differentiates separate subgroups based on  
253 movement direction in which the impairment is most apparent and linked to pain  
254 provocation. Whether the direction inferred from MSI classification parallels direction-  
255 specific differences in trunk mechanics or muscle activity requires clarification. Also,  
256 it is unclear how a tight control subgroup might relate to the MSI classification.

#### 257 **4.4 Do clinical tools allow reliable classification of motor control?**

258 Current subgrouping methods were not specifically developed to classify  
259 patients based on motor control issues. Nevertheless, the fact that these methods

reliably arrive at subgroups that likely show partial overlap with those that might be found using the laboratory-based biomechanical and electromyography measurements used in motor control studies is promising. Objective measurements may add to consistency, validity and reliability of subgrouping and might have as additional benefit that they would permit consideration as a measure of treatment effects, if found responsive. In several of the classification systems, motor control is assessed in a direction specific manner. The relation between directional specificity of the clinical presentation and underlying changes in motor control and their effects require further study.

## 5. Is subgrouping based on motor control clinically useful?

Subgrouping based on motor control can be considered of clinical value if it has heuristic value, meaning, if assignment of a patient to a specific subgroup implies a specific treatment and if such targeted care is more effective than a one-size-fits all approach. Review of biomechanical, electromyography and modelling studies reveals a spectrum of changes in motor control in LBP with extremes of tight control and loose control.<sup>94</sup> Motor control changes at both ends of this spectrum have the potential to lead to suboptimal mechanical loading of the spine, but in different ways. This implies that modification of motor control has potential benefit with opposite treatment targets for the subgroups at either end. Loose control implies that enhancement of muscle activity is required, whereas tight control implies an emphasis on reduction of muscle activity.<sup>36</sup> It should be kept in mind that these interpretations are based on the assumption that these motor control patterns are maladaptive and clinical benefit will be derived from “correction” of the strategy. For each of the motor control measures that have been used in research, there is a subgroup of individuals with LBP who show ‘normal’ motor

285 control,<sup>94</sup> which suggests that this subgroup would *not* benefit from MCE. There is  
286 some evidence to support this hypothesis. Two clinical trials have shown less clinical  
287 improvement for individuals without evidence of a motor control deficit (poor control  
288 of transversus abdominis) at baseline.<sup>25, 87</sup> On the other hand, baseline findings on trunk  
289 muscle control were not correlated to clinical improvements in two other studies.<sup>50, 102</sup>

290 The question whether subgrouping based on motor control is useful can only be  
291 answered after appropriate clinical trials have been performed. To date there is mixed  
292 evidence whether interventions that target treatment based on motor control  
293 subgrouping achieve better outcomes than non-targeted treatments for LBP. Two RCTs  
294 with a focus on matching exercise to movement subgroups showed no benefit over  
295 general exercise in the long-term primary outcomes of pain and disability in chronic  
296 LBP.<sup>2, 45, 74</sup> In contrast, several recent RCTs demonstrated superior long term outcomes  
297 with individualized MCE in people with chronic LBP, based on an integrated  
298 subgrouping approach, one included assistance of a wearable biofeedback device<sup>39</sup> and  
299 another used an individualized approach to targeting relevant cognitive, motor control  
300 and lifestyle factors in people with chronic LBP.<sup>98</sup> A missing link is whether the clinical  
301 effects in these trials were related to a change in motor control. The possibility that  
302 other factors mediated the positive outcomes remains to be excluded. Given the  
303 preceding discussions it can be concluded that an affirmative answer is plausible and  
304 hence subgrouping based on motor control would merit further research.

305

## 306 **6. Are subgroups based on motor control mutually exclusive?**

307 Mutual exclusivity of subgroups implies that an individual can only be allocated  
308 to a single subgroup and would only be expected to respond to the ascribed course of  
309 management. With the exception of the MDC, existing clinical approaches, described

310 above, force assessors to allocate patients to a single subgroup, making it difficult to  
311 evaluate whether subgroups are mutually exclusive. Some differences in subgroup  
312 allocation between testers (inter-tester variability) implies that overlap may exist.

313         The tight and loose control subgroups that are apparent in biomechanical and  
314 electromyography studies would appear to be mutually exclusive, but with some  
315 considerations. First, how the groups are separated is not yet clear. Literature indicates  
316 that a group with “normal” control sits between those with tight and loose control. The  
317 measures that would be considered to differentiate the groups and the cut-off scores  
318 have not been established. Second, some patients may even present with elements of  
319 both subgroups: an overall tight presentation may be combined with elements of low  
320 stiffness in specific directions or of specific joints. For instance, increased activity of  
321 some muscles with pain, causing an overall increase in trunk stiffness, may coincide  
322 with reduced activity in other muscles.<sup>35</sup> While the overall change in muscle activity  
323 would allow tight control over thorax movements, it might coincide with a reduced  
324 control over segmental movements in a specific direction in view of the inhibition of  
325 some muscles. Third, motor control patterns are somewhat context dependent. It cannot  
326 be excluded that an individual may show ‘loose’ control in one situation, and show tight  
327 control in another situation; for example, a more threatening task may elicit a  
328 compensatory strategy with high levels of muscle activity regardless of strategy adopted  
329 in a less threatening situation.<sup>92</sup>

330         Subgrouping of patients with LBP purely on the basis of motor control assumes  
331 that motor control and tissue loading is relevant for the underlying persistence of pain  
332 in all patients, yet not all pain is the same. As highlighted earlier, pain can be broadly  
333 considered to primarily involve nociceptive, neuropathic or central sensitization  
334 mechanisms. In the presence of a primary nociceptive mechanism, loading of tissue is

335 likely to be relevant. The motor control adaptation may be adaptive and potentially  
336 helpful or maladaptive and relevant for persistence. When the mechanism is  
337 neuropathic, loading may be relevant with respect to loading of neural tissue.

338         In the presence of primarily central sensitisation pain, pain may persist despite  
339 absence of ongoing nociceptive input from the tissue and treatment targeted to  
340 optimisation of tissue loading through motor control training is unlikely to address the  
341 underlying mechanism, but could aid recovery through exposure to healthy movement.  
342 Consideration of pain mechanisms in a motor control subgrouping approach could take  
343 two main paths. First, the approach may involve a hierarchical process where the first  
344 step is to identify the primary pain mechanism. If a nociceptive (and perhaps  
345 neuropathic) mechanism is identified, then the patient would be characterized  
346 according to motor control presentation. If central pain mechanisms are identified then  
347 an alternative course of management is planned to address the pain mechanism (pain  
348 coping training, pain education, fear-deconditioning, etc), without primary  
349 consideration of motor control. Second, the approach could also involve a parallel  
350 process whereby all patients are assessed on the basis of pain mechanism and motor  
351 control and a treatment package is developed that includes components of intervention  
352 targeted to both domains, based on the presenting features. This latter model assumes  
353 that pain mechanism and motor control phenotypes are not mutually exclusive and  
354 some central sensitisation may be present in those with nociceptive/neuropathic pain  
355 (which is highly probable) and some nociceptive input may contribute to maintenance  
356 of pain state. In each case assessment of the dominant pain mechanism requires  
357 attention. Several instruments have been proposed.<sup>67, 68, 76-80</sup> These assessments require  
358 further validation and development towards a clinical tool.

359 To be comprehensive, in addition to pain mechanism, the diagnostic system  
 360 requires evaluation of patients across multiple biological, psychological and social  
 361 dimensions. These would include features relevant to motor control such as patterns of  
 362 pain provocation and relief,<sup>20-22, 62, 73</sup> muscle atrophy and weakness,<sup>55, 56</sup> proprioceptive  
 363 impairment,<sup>63, 86</sup> as well as differentiation of psychological features including pain  
 364 beliefs and fear of pain or re-injury,<sup>57, 100</sup> depression, catastrophising, self-efficacy, and  
 365 social issues.<sup>70</sup> An important consideration is that domains are not independent. For  
 366 instance, measures of motor control may reflect psychological factors such as fear of  
 367 pain.<sup>31, 44, 58, 71, 88-90</sup> Overlap of domains, particularly some of the sensory and motor  
 368 domains may reflect redundancy and may allow simplification of diagnostic schemes.  
 369 Furthermore, in many cases characterization of patients occurs along a continuous  
 370 scale, not necessarily yielding exclusive subgroups.<sup>c.f. 67</sup> In the parallel model, rather  
 371 than fitting explicit subgroups, it may be more ideal to profile patients across these  
 372 dimensions rather than fitting into explicit subgroups, allowing outcomes to be  
 373 monitored with respect to each of the dimensions, in line with the MDC approach.<sup>67</sup>  
 374 Comprehensive profiling of patients or subgrouping may also benefit from  
 375 being embedded in a system with stratification based on prognosis.<sup>c.f. 1</sup> Prognostic  
 376 stratification tools such as StartBack<sup>34</sup> are based on the belief that many LBP cases  
 377 recover within several weeks irrespective of treatment,<sup>37, 101</sup> and that more  
 378 comprehensive management should be reserved for those with greater likelihood of  
 379 poor outcome. These tools attempt to predict which patients belong to this group, to  
 380 avoid unnecessary diagnostic procedures and over-treatment in the “low-risk” group.  
 381 The StartBack tool specifically identifies greater psychological prognostic barriers for  
 382 recovery in the “high-risk” group and recommends psychologically informed treatment.  
 383 In the “moderate-risk” group, comprehensive treatment is recommended and our model



384 of patient characterisation across multiple domains including motor control (with or  
385 without allocation to subgroups) is likely to be most relevant in this group.

386

## 387 7. *Potential role for objective tests of motor control in patient assessment*

388 Although clinical assessments can be used to reliably allocate patients to  
389 subgroups, there may be additional benefit for interpretation of underlying mechanisms  
390 and objectively and sensitively tracking recovery by objective measurements. Further  
391 research is needed to verify that individuals can consistently be classified into motor  
392 control-based categories based on a minimal battery of objective tests.

393 Motor control of the trunk comprises modulation of intrinsic stiffness through  
394 tonic muscle activity, anticipatory control, and feedback control.<sup>94</sup> To characterize trunk  
395 control in LBP it may be necessary to evaluate these different aspects with dedicated  
396 tests. Given the emphasis on directional preferences or directional impairments in  
397 current classification systems, objective testing should probably be multi-directional.  
398 The potential existence of positive (adaptive) and negative (maladaptive) subcategories  
399 of both tight and loose control requires further consideration. An additional  
400 consideration is that adapted motor control may be context dependent; for example,  
401 individuals with LBP may show more pronounced changes when they perceive the task  
402 that they perform as threatening in terms of pain provocation or re-injury. These  
403 considerations would suggest that a comprehensive set of tests and test conditions is  
404 necessary to characterize motor control in LBP. This might cast some doubt on the  
405 practical applicability of subgrouping based on objective measures of motor control.  
406 As an alternative approach, assessment of trunk control in daily life could be considered  
407 as an efficient way to obtain a large amount of ecologically valid information with  
408 limited effort, although substantial work would be required to develop and test such an

409 analysis. Comprehensive testing may be shown to yield redundant information. If motor  
410 control impairments in LBP can be sufficiently characterized based on a limited number  
411 of tests, this would greatly simplify clinical implementation.

412

413

## 414 **8. Conclusions**

415 Targeting of treatment for the management of LBP based on motor control  
416 presentation may be helpful. Although clinical trials provide evidence for some aspects  
417 of the approach and motor control literature provides support for the plausibility, there  
418 are major gaps remaining in the literature. Large RCTs are required to compare the  
419 benefit of interventions that are matched to motor control presentation against  
420 treatments that are not matched. Further insight might be gained from the establishment  
421 of a minimal battery of objective tests that aid in the identification of the specific motor  
422 control phenotypes. Approaches to allocate patients to subgroups to guide treatment or  
423 alternatively to evaluate patients across a range of domains and measures should be  
424 compared for their effectiveness. Both imply personalisation of care to the individual  
425 patient, and both methods have positive and negative features.

426

## 427 **Acknowledgements**

428 The authors would like to thank dr. Peter O' Sullivan and dr. Julie Fritz for reviewing  
429 a previous version of this paper.

430

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